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ORIGINAL RESEARCH

Heat Strain Imposed by Toxic Agent Protective Systems

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Cadarette BS, Levine L, Staab JE, Kolka MA, Correa M, Whipple M, Sawka MN. *Heat Strain imposed by toxic agent protective systems.* **Aviat Space Environ Med 2001; 72:32–7.**

This study evaluated physiological heat strain from two developmental toxic agent protective systems compared with the standard Toxicological Agent Protective (TAP) suit during exercise-heat stress. Eight subjects (six men, two women) completed three experimental trials, at 38°C, 30% rh, wearing: 1) Self Contained Toxic Environment Protective Outfit (STEPO) with rebreather (STEPO-R); 2) STEPO with tether (STEPO-T) or 3) the standard TAP. The STEPO systems provided effective body cooling of: STEPO-R, 200 ± 36 W; and STEPO-T, 186 ± 59 W. TAP had no cooling. All experimental trials used treadmill walking at 0.89 $m \cdot s^{-1}$, 0% grade at exercise/rest cycles of 20/10 min for 240 min. Metabolic rates for the treatments were: STEPO-R, 298 ± 26 W; STEPO-T, 299 ± 34 W; and TAP, 222 ± 40 W. Rate of heat storage was less ($p < 0.05$) in STEPO-R (37 ± 8 $W \cdot m^{-2}$) and STEPO-T (38 ± 12 $W \cdot m^{-2}$) than in TAP (77 ± 15 $W \cdot m^{-2}$). Sweating rate was less ($p < 0.05$) in STEPO-T (10.0 ± 4.8 $g \cdot min^{-1}$) than in TAP (23.8 · 11.4 $g \cdot min^{-1}$). There was no difference between STEPO-R (12.3 ± 5.6 $g \cdot min^{-1}$) and the other two uniform systems. Subjects did not complete targeted exposure times of 240 min. Exposure time was longer ($p < 0.05$) in STEPO-R (83 ± 22 min) and STEPO-T (106 ± 39 min) than in TAP (46 ± 10 min). Predicted time to 39.0°C was less ($p < 0.05$) in TAP (69 ± 20 min) than in either STEPO-R (226 ± 124 min) or STEPO-T (244 ± 170 min). The results of this study show that cooling in STEPO significantly reduced heat storage relative to TAP. The new generation toxic cleanup uniform systems effectively reduced heat stress and increased work capabilities compared with the standard TAP suit.

Keywords: protective clothing, toxic environments, heat stress, human physiology, exercise.

THE MANAGEMENT and decommissioning of dangerous chemical sites requires the storage, maintenance, clean-up, and destruction of highly toxic substances. It is essential that workers who clean up spills or otherwise handle the toxic agents routinely wear protective uniform systems. Prior to 1988, the Toxicological Agent Protective (TAP) uniform was the U.S. Army standard for use in toxic environments which pose an "immediate danger to life and health" (IDLH) (**Appendix**). These protective clothing systems are impermeable to water and have a high level of insulation which impose marked heat stress on the users (9,10,15).

By 1987, in accordance with the Occupational Safety and Health Administration's safety limits for allowable exposure to chemical warfare agents, the Surgeon General of the Army and the Army Materiel Command identified the need for a new protective ensemble. A new uniform system, the Self-Contained Toxic Environment Protective Outfit (STEPO) was developed. STEPO was designed for personal protection in highly toxic, unknown or oxygen deficient environments that pose an IDLH. STEPO systems were designed to be totally encapsulating and self-contained, not relying on filtered breathing air as does the TAP suit. An interim STEPO (STEPO-I) was developed and introduced in 1988 to replace the TAP suit in IDLH environments (9,10,15). The STEPO-I when worn in a tethered air configuration allowed greater evaporation of sweat and a longer endurance time than either the TAP suit or STEPO-I worn with a backpack rebreather system, and liquid cooled vest. However, the STEPO must sometimes be worn without the tethered line and when worn in the rebreather configuration, was found to impose several severe ergonomic design limitations (9,15).

A new generation of STEPO was designed to outperform the STEPO-I in terms of reduced heat stress, improved load carriage and improved flame resistance, as well as both industrial chemical and chemical warfare agent protection. The purpose of this study was to compare candidate STEPO and TAP uniform systems for the heat strain elicited during a standardized exercise heat stress test. The study was designed to provide information on the safety of wearing the STEPO during an intended 4-h maximal stay time system. Eight volunteers were tested in a repeated measures study wearing each of the three uniform configurations.

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METHODS

Equipment

The candidate STEPO system is designed for maximal use time of 4 h from donning to doffing in ambient temperatures up to 38°C (100°F) with no ambient dew point limitations specified. The system includes an impermeable suit, which totally encapsulates the body. This candidate system also includes a personal, vapor compression, microclimate-cooling system (MCC) with a rated cooling capacity of 375 W at a 35°C ambient temperature. The MCC circulates a 25% glycol/water solution through a full body-cooling undergarment (head, torso, legs) with over 300 ft of integral, small diameter cooling lines. The refrigerant in the MCC is HFC 134A. While the MCC is designed to be battery operated or run off vehicle power, for the current study power was supplied through an adapter using a standard AC output. The MCC unit was floor mounted for this research study, but normally would be carried to the work site, then set on the ground while duties are completed. The weight of the MCC unit including batteries is 10 kg.

Respiratory protection in the candidate STEPO is provided in one of two ways. The users wear either a self-contained breathing apparatus (STEPO-R) with a maximum 4-h capability, or a tethered airline to a safe air supply while in the toxic environment (STEPO-T). The total STEPO-R configuration including uniform, cooling garment and respiratory system, but without the MCC, weighs approximately 27 kg. The total STEPO-T configuration including uniform, cooling garment and emergency breathing apparatus, but without the MCC, weighs approximately 22 kg. The standard TAP suit as worn in operations is 9.5 kg. Additional details about the TAP suit and the two STEPO configurations can be found in the Appendix.

Subjects

Eight volunteers (six men and two women) served as subjects for the experimental trials after completing medical examinations to assure there were no underlying problems. The subjects mean ± SD age, height, weight and % body fat are 24 ± 4 yr, 172 ± 10 cm, 75.1 ± 11.4 kg and 20.9 ± 6.1%. All subjects were fully informed of the purpose, procedures and potential risks of the study and signed a statement of informed consent. Investigators obtained appropriate Institutional Review Board approval and adhered to guidelines established for research in humans.

Experimental Design

The experimental procedures employed were consistent with those recommended for test candidate chemical protective systems (11). Preliminary testing consisted of anthropometric measures (height, weight, estimate of per cent body fat by subcutaneous skinfold thickness at four sites (5)). The subjects were familiarized with the STEPO and TAP systems, and metabolic rates were collected to measure the energy cost of exercise and rest periods. The subjects then completed 5 d of exercise-heat acclimation before experiments began (7). After completing the exercise-heat acclimation program, the subjects completed 3 experimental trials, one in each of the 3 uniform configurations, in a counterbalanced order.

Procedures/Measurements

Metabolic rates were determined on 5 of the 8 subjects during familiarization with each of the 3 uniform configurations. Metabolic rates were determined by open circuit spirometry during both exercise and while seated, so a proper work-rest scenario could be calculated using time-weighted metabolic rates. Prior to the heat stress tests, the subjects were familiarized with walking on the treadmill while wearing the STEPO-R, STEPO-T and standard TAP uniform configurations. The energy cost of walking on the treadmill at 0.89 m $\cdot$ sec^{-1}, 0% grade and at seated rest while wearing these 3 uniforms was calculated. Expired respiratory gases were collected and analyzed using a Sensormedic 2900 Metabolic Cart. Using rest/exercise cycles of 10/20 min for the 4-h tests, the time weighted mean ± SD energy cost for the subjects in each uniform configuration was STEPO-R 298 ± 26 W, STEPO-T 299 ± 34 W and TAP 222 ± 40 W. These metabolic rates were similar to those measured during simulated field tests with workers performing realistic job scenarios while wearing STEPO (3). However, unlike the field test, the energy expenditure in the current study was regulated with predetermined steady-state treadmill walks interspersed with standardized rest periods.

The subjects completed a 5-d exercise-heat acclimation program consisting of treadmill walking at 1.56 m $\cdot$ sec^{-1} on a 4% grade for two 50-min exercise sessions with 10 min of seated rest prior to the first walk and between the two walks. Environmental conditions were 40.0°C T_{db}, 19.4°C T_{dp}, 30% rh, and subjects wore shorts, t-shirts and athletic shoes. They were instrumented to monitor heart rate (HR) and core temperature (T_{re}). Subjects were given at least 250 ml of water or a commercial glucose-electrolyte drink before entering the heat chamber each day. During exercise, subjects were encouraged to drink water. Pre- and post-exercise weights were charted each day to assure that subjects did not undergo progressive dehydration.

Following heat acclimation, the subjects completed 3 experimental tests. All tests were performed in an environmental chamber set at 38°C, 30% rh, no wind and at approximately the same time of day. In each STEPO and TAP experimental test, the subjects attempted 240 min of total exposure with repeated rest/exercise cycles of 10 min rest and 20 min of treadmill walking. The treadmill was set at 0.89 m $\cdot$ sec^{-1}, 0% grade for all experiments. Any given test was terminated at the predetermined endpoint of heat exposure (240 min), predetermined core temperature endpoint (T_{re}=39.5°C) or HR endpoint (90% age predicted maximal HR) criteria. Experimental tests were also terminated whenever a subject exhibited the symptoms or signs of an impending heat illness, when a subject chose to terminate, or at the discretion of the medical monitor or investigator.

The subjects performed the experiment in the two

STEPO configurations and the TAP suit in a counterbalanced order to avoid an order effect on results. On each experimental test day, the subjects received at least 500 ml of a glucose-electrolyte drink immediately after obtaining the nude weight at arrival. This was the only liquid available to them until conclusion of the day's experimental test. Morning and afternoon test sessions were conducted. Subjects always reported at the same starting time, and there were approximately 44 h between tests for recovery and rehydration.

During all tests, T_{re} was measured by a flexible thermocouple probe inserted to a depth approximately 10 cm beyond the anal sphincter. During experimental tests, mean weighted skin temperature ($\bar{T}_{sk}$) was calculated from a four site skin thermocouple harness (chest, arm, thigh, calf) (16). HR was obtained from an electrocardiogram (chest electrodes, CM5 placement), displayed continuously on an oscilloscope cardiotachometer unit. Heat storage (S) in $W \cdot m^{-2}$ was calculated from the equation $S=[(m_b \cdot c_b)/A_D] \cdot (dT_b/dt)$, where m_b is the mean body weight (kg), during the experiment; c_b is the specific heat constant ($0.965\ W \cdot h \cdot {}^{\circ}C^{-1} \cdot kg^{-1}$); A_D is the DuBois surface area (m^2); dT_b is the change in mean body temperature (°C) where $T_b=0.2 \cdot \bar{T}_{sk}+0.8 \cdot T_{re}$; and dt is the exposure time (h). Whole body sweating rates were calculated from changes in pre- to post-test nude weights with correction for any liquids ingested or urine voided subsequent to the first morning weight.

Subjects entered the chamber and were connected for on-line collection of T_{re}, T_{sk}, and HR. Data on flow rate and temperature change of the coolant supplied to the cooling garments in the two STEPO configurations were also collected. The subjects sat for 10-min followed by 20 min of walking at $0.89\ m \cdot s^{-1}$ on a level treadmill. This pattern was repeated throughout the attempted 4-h tests for STEPO and TAP.

Statistical Analysis

Data were provided on the subjects' endurance time, final core temperature (T_{ref}), final heart rate (HR_f), heat storage (S) and whole body sweating rate in each of the three uniforms for end point comparison. Sweating rate data was available and calculated on five subjects. ANOVA were conducted for core temperature (T_{re35}), ($\bar{T}_{sk35}$) and heart rate (HR_{30}), at 35 and 30 min of exposure, respectively, when all subjects were still present in all tests. ANOVA was also performed on calculated time for core temperature to reach 39°C, based on the slope of the individual core temperature responses during the first exercise bout. Wherever possible, data from flow rate and inlet/outlet coolant temperature change were used to calculate the heat removed by the MCC. This was then used to calculate the mean cooling provided within each STEPO configuration. Data to calculate cooling were available on only six subjects as equipment malfunctions in the measuring devices affected at least one day's data on the other subjects. The Tukey test was used to isolate the uniform systems which differed from each other at the $p < 0.05$ level. Because both males and females were used as subjects, statistical analyses were also performed separately on the six males only. There were no differences in the results between systems when looking at the male only data, so all results reported are on the eight subjects as a single group.

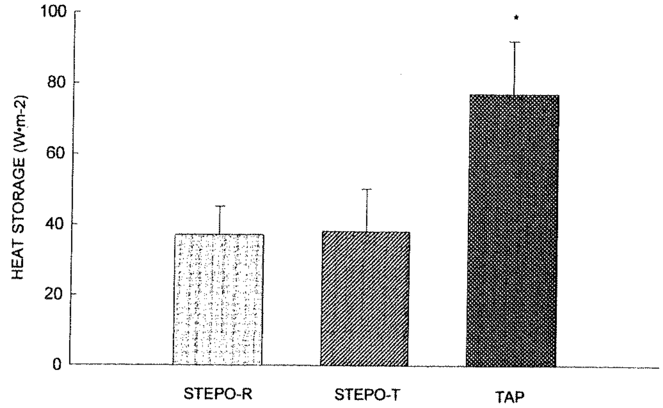

Fig. 1. Mean ± SD heat storage in the STEPO and TAP uniforms during exercise at 38°C, 30% rh. *Significantly different from both STEPO configurations ($p < 0.05$).

RESULTS

Mean endurance times ±SD for the three uniforms were STEPO-R, 83 ± 22 min; STEPO-T, 106 ± 39 min and TAP 46 ± 10 min. TAP endurance was shorter ($p < 0.05$) than both STEPO configurations, which were not different from each other. Mean final core temperature ±SD for the three uniforms were STEPO-R, 37.3 ± 0.4°C; STEPO-T, 37.8 ± 0.4°C; TAP, 38.1 ± 0.5°C. Mean final HR ± SD for the three uniforms were STEPO-R, 126 ± 22 bpm; STEPO-T, 121 ± 21 bpm; and TAP, 138 ± 17 bpm. Neither the final values for core temperature or HR could be statistically analyzed, as they occurred at different times in each volunteer. The mean heat storages for the uniforms were $37 \pm 8\ W \cdot m^{-2}$ for STEPO-R, $38 \pm 12\ W \cdot m^{-2}$ for STEPO-T, and $77 \pm 15\ W \cdot m^{-2}$ for TAP (**Fig. 1**). Heat storage in TAP was significantly greater than in both the STEPO configurations. In the five subjects with whole body sweating rate data available in all configurations, the sweating rates were $12.3 \pm 5.6\ g \cdot min^{-1}$ in STEPO-R, $10.0 \pm 4.8\ g \cdot min^{-1}$ in STEPO-T and $23.8 \pm 11.4\ g \cdot min^{-1}$ in TAP. Sweating rate in TAP was significantly greater ($p < 0.05$) than in STEPO-T. In the six subjects with cooling data available in both STEPO configurations, the total cooling provided by the vapor compression MCC was 200 ± 36 W for the STEPO-R configuration and 186 ± 59 W for the STEPO-T configuration (**Fig. 2**).

At 35 min of heat exposure, the mean core temperatures for the three uniforms were 37.2 ± 0.2°C for STEPO-R, 37.3 ± 0.2°C for STEPO-T, and 37.7 ± 0.2°C for TAP. The 35 min core temperature in TAP was greater ($p < 0.05$) than both STEPO configurations. At 35 min of heat exposure, the mean skin temperatures for the three uniforms were 34.4 ± 1.6°C for STEPO-R, 34.7 ± 1.0°C for STEPO-T and 37.8 ± 0.2°C for TAP. Mean skin temperature in TAP was greater ($p < 0.05$) than in both STEPO configurations. HR was taken at 30 min rather than at 35 min as this was the last minute of the exercise bout. At 30 min of heat exposure, the mean HR for the three uniforms were 101 ± 15 bpm for

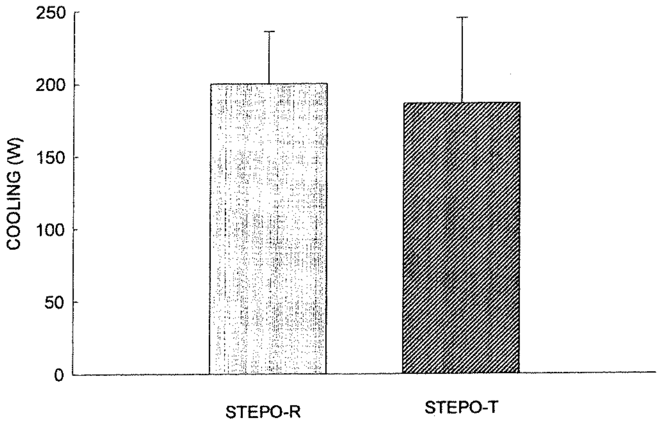

Fig. 2. Mean ± SD cooling in Watts provided by the vapor compression cooling system in each STEPO configuration during exercise at 38°C, 30% rh.

STEPO-R, 112 ± 10 bpm for STEPO-T and 131 ± 14 bpm for TAP. The mean 30-min HR in TAP was greater ($p < 0.05$) than in both STEPO configurations.

The calculated times to core temperatures of 39°C in each condition were determined from the slopes of core temperature increase from the first exercise bout. These values were used based on previous cooling studies which show a linear core temperature response when constant cooling is provided (2,6). The calculated times to core temperatures of 39°C were 226 ± 124 min for STEPO-R, 244 ± 170 min for STEPO-T and 69 ± 20 min for TAP (**Fig. 3**). The calculated time for TAP was significantly less than for both STEPO configurations.

DISCUSSION

The reduced heat strain and increased exposure times exhibited by the subjects when wearing the STEPO configurations compared with TAP, are clearly a result of the effects of the microclimate cooling systems. These improved physiological responses are achieved even though the STEPO configurations impose a higher metabolic cost due to their heavier weights. Microclimate cooling has long been shown to reduce heat strain when worn with protective clothing (17,18). This was the first study to systematically track these cooling benefits while subjects performed the same task, but at different metabolic costs due to equipment differences. Benefits from microclimate cooling such as decreased cutaneous peripheral blood flow (1), decreased sweating rates (17,18), and lower skin temperatures (17) result in lower core temperature, reduced heart rates and improved performance time in the heavier uniform configurations.

The stay times for both the STEPO-R and STEPO-T uniform configurations were respectively 1.8 and 2.3 times that of the TAP. Therefore, not only were the final core temperatures of the subjects in the 2 STEPO configurations more than 0.35°C lower than in the TAP uniform, but this measurement was taken after approximately twice as much heat exposure as in TAP. Final HR were likewise lower in both STEPO systems than in TAP, again after approximately twice as much heat exposure. These findings are likely the result of the individual cooling system, as blood which did flow to the periphery was cooled by the garments, helping to reduce heat storage and lessen the amount of cutaneous vasodilation necessary, thereby maintaining a lower heart rate. The whole body sweating rate indicated a significant difference only between the STEPO-T and TAP. There was also a trend toward a large difference in the rate between TAP (23.8 g ± min^{-1}) and STEPO-R (12.3 g ± min^{-1}). However, this difference was not statistically significant, probably as a combination of large SD from the mean and the small number of subjects ($n = 5$). These lower sweating rates in the STEPO systems are indicative of the benefits provided by MCC.

The exposure times in both STEPO configurations as well as in TAP were less than the desired 240 min. In part, this was a result of the naive subject population who were not used to being totally encapsulated for extended periods, as are chemical site personnel. In addition, the decision to use a hot-dry acclimation program did not familiarize the subjects with the sensation of total skin wettedness, which also probably impacted negatively on their stay times in the protective clothing. It must also be noted that even with the 200 W and 186 W of cooling delivered to the body in the 2 STEPO configurations, the subjects still experienced approximately 40 $W \cdot m^{-2}$ of heat storage resulting in elevated core temperature and HR (13,14). It can be presumed that this level of heat storage would likely have a more rapid impact on individuals who were neither heat acclimated nor accustomed to being encapsulated in impermeable clothing, leading to subjective feelings of heat strain or exhaustion.

An additional difference in the 2 STEPO configurations, which might explain the different stay times in them configurations, as well as the difference between them and TAP, could be in the temperature of the breathing air. In TAP, the inspired air was always hot, approximating the chamber temperature of 38°C, while exhalation of saturated air increased the water vapor pressure inside the mask. In the STEPO-T, breathing air was supplied by compressed gas, which cools as it expands leaving the tank, and in the STEPO-R as breathing air was re-circulated through the CO_2 scrubber, it was passed over an ice pack to lower the temperature prior to inhalation. Levels of thermal comfort

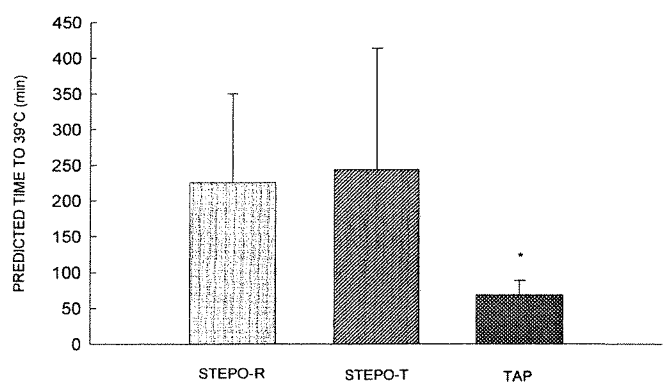

Fig. 3. Mean ± SD predicted time in minutes to reach core temperature of 39°C in the STEPO and TAP uniforms during exercise at 38°C, 30% rh. *Significantly different from both STEPO configurations ($p < 0.05$).

related to facial skin temperature have been developed which show that skin temperatures of 34.5°C at rest and 31°C during exercise are rated as comfortable (4,8,12). It is possible that these perceptions had some effect on the subjects, as there were instances in STEPO-R when subjects reported the air to the facemask starting to feel warm shortly before they asked to be removed. Once they were undressed, it was found that the air re-cooling ice packs were completely used up during the exercise trial. The design of the STEPO-R is such that the rebreather system is completely enclosed by the STEPO garment, so there is no way of replacing the air re-cooling ice packs without compromising the individual in a chemical environment. The same is not true in STEPO-T, which provides the compressed gas on demand with every breath and will maintain a constant temperature throughout exercise.

A further and important difference between this test and field trials showing 4-h exposure times was the enforced-pace, steady-state walking imposed on the current test subjects as opposed to the varied, self-paced routine duties of the field trials. Even though the mean metabolic heat production was similar in both the field trials and laboratory experiments, the ability to control the pattern of work and rest and, therefore, rate of heat storage and heat removal, can make a difference in an individual's ability to sustain an average work load. It should also be noted that the predicted times to reach core temperatures of 39°C for both STEPO configurations was around 4 h. This core temperature (39°C) is both within the safety limits of this study and within the maximal expected temperatures for the toxic chemical worker completing some tasks in a hot environment. The primary concern of these experiments was to determine the safety and efficacy of wearing the STEPO uniforms in an uncompensable heat stress situation. Based on the findings, it is our assessment that if the batteries used in the field can assure a constant flow rate and temperature through the cooling garment, the STEPO uniforms as currently configured are superior to the TAP suit in reducing heat strain.

CONCLUSIONS

The new generation of toxic chemical protective uniform systems can effectively reduce heat strain and increase work capabilities, because of the MCC included in the systems. It has not yet been determined what cooling system will provide the most favorable ratio of heat removal to equipment weight. All of the improvements to the STEPO systems, which make them a safer alternative to wearing the TAP suit, also come with a significant weight and therefore metabolic burden to the toxic chemical worker. While STEPO improves the workers' safety through enhanced respiratory and clothing protection, and increases work capacity through MCC, it is important that ergonomic improvement to weight distribution be considered. Developers should also be alert to any technological breakthroughs, which will lessen the metabolic burden on the user, such as lighter materials. Efforts should also be directed toward increasing the effective cooling delivered to the body from the vapor compression system.

APPENDIX

TAP Suit Description

The TAP consists of a coverall type, button-up suit fabricated entirely of butyl rubber-coated nylon material. The TAP is worn with butyl rubber boots; an M17 or M40 protective mask for respiratory protection; a butyl rubber hood which covers the head, neck and shoulders; and butyl rubber gloves. The TAP suit is worn over cotton sateen shirt, trousers, gloves and socks, all of which are impregnated with chlorinated paraffin. When worn under the TAP, the impregnated clothing outfit is designed to protect the wearer from blister agent vapors. The TAP suit uses no microclimate cooling. The standard TAP suit including chemically impregnated undergarment weighs approximately 9.5 kg.

STEPO System Descriptions

The STEPO system consists of a totally encapsulating suit; 2 clean-air breathing systems, 1 self-contained and 1 for tethered use; a microclimate cooling system (MCC) and a communications system. The STEPO outer shell is a 1-piece garment with integral booties, back pod (to enclose backpack rebreather), visor, air-tight closure, exhaust valves, pass through, support harness and glove assembly. The material is light in weight and color, is flexible and is composed of PFTE (Teflon) and NOMEX®. The fabric has an integrated monomer film which helps decay static charge across the surface. The visor, incorporated into the head portion of the suit, provides a wide field of vision. The visor is a multi-laminate film consisting of a 10 mil fluorinated ethylene polypropylene (FEP) film which is machine-laminated to a 7–10 mil hydrophilic film. The FEP is permanently welded to the suit. The hydrophilic film provides anti-fogging. The gloves (butyl viton) for the system are interchangeable, depending on the chemical hazard.

The MCC has a rated cooling capacity of 375 W at an ambient temperature of 35°C. For a 4-h mission, the liquid based cooling system is supplied 280 W of cooling at 18°C delivery temperature. The system is composed of a full body cooling garment (head, torso, legs) with at least 300 ft of integral, small diameter cooling lines, umbilical hose, MCC unit and power supply (4 BA5590 lithium batteries). Refrigerant in the MCC unit is HFC 134A, and in the hoses is 25% propylene glycol in distilled or de-ionized water. The unit is carried to the work site and set on the ground during operations. The weight of the cooling unit with batteries is 10 kg.

The self-contained breathing apparatus (R, Biomarine BioPak 240) has a 4-h capability and was redesigned for the STEPO program. The improvements from the standard BioPak 240 for the STEPO program are reduced size (front to back profile reduced ~6 in) and weight (reduced by 6.2 lbs). The weight of the STEPO-R system, carried as a backpack under the STEPO shell, is 15 kg. The system is composed of a full face piece, respirable gas container, gas pressure gauge, service life indicator, hand-operated valves, O_2 relief system, adjustable harness system, optical inserts, O_2 source, positive pressure breathing bag, a relief system to vent excess breathing O_2 outside the suit. The closed-circuit rebreather circulates exhaled air through a CO_2 scrubber. The effluent is then mixed with an O_2 stream supplied from a compressed air bottle, and is then reintroduced into the respirator face piece where it is inhaled. Exhalation resistance is 2 in of water and inhalation resistance is 4 in of water. The mask contains a speaking diaphragm and lens insert to reduce fogging. The STEPO-R air is cooled by use of a frozen gel tube to lower the temperature of the rebreathed air.

The tethered airline (STEPO-T) with an emergency breathing apparatus (EBA) is a combination of two breathing systems. The EBA is redesigned from an existing NIOSH approved system. The STEPO-T has a supplied air system operated at an inlet pressure of 110–125 psig with a supply hose of up to 300 ft in length. The 30-min EBA is an aluminum tank, fully wrapped with fiberglass and weighs 7 kg when charged to 4500 psig. A first stage regulator located at the cylinder neck reduces the cylinder pressure to 135–155 psig. A pressure demand valve located on the face piece provides air to the user and maintains a positive pressure to the face piece. The system is equipped with a visual pressure gauge and an audible low-pressure alarm, which sounds at 25% of cylinder operating pressure.

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